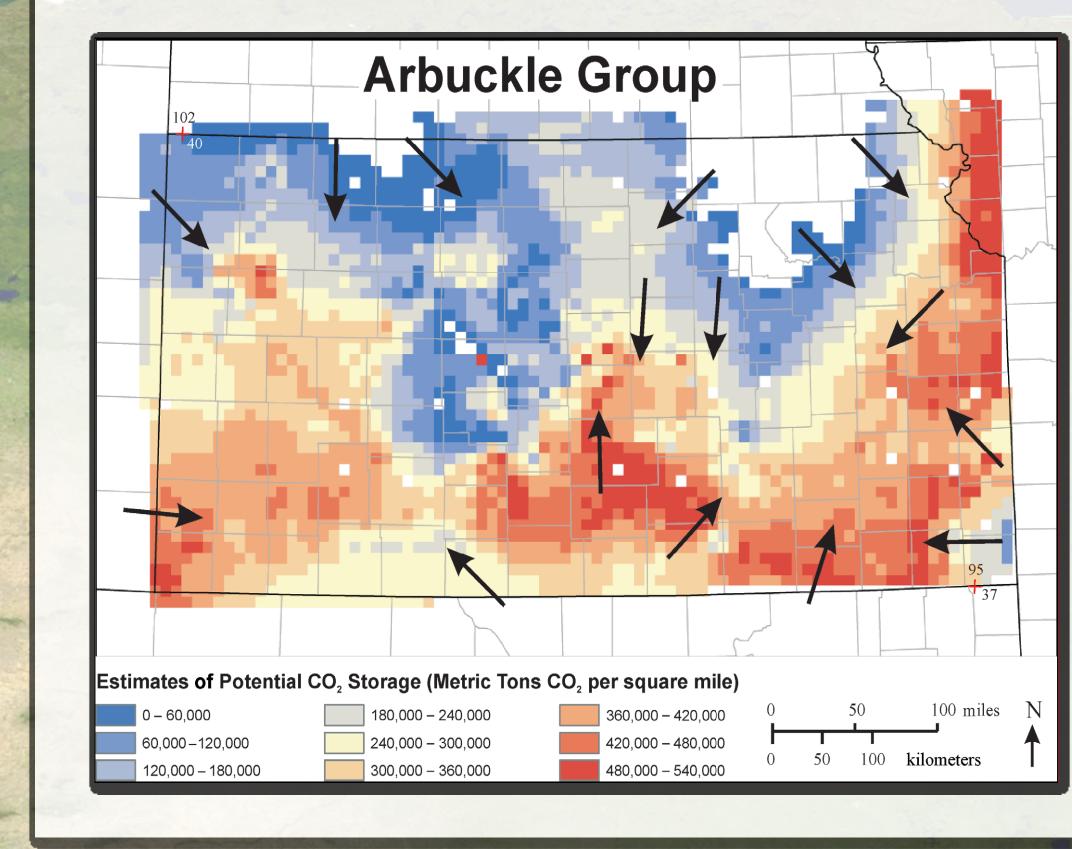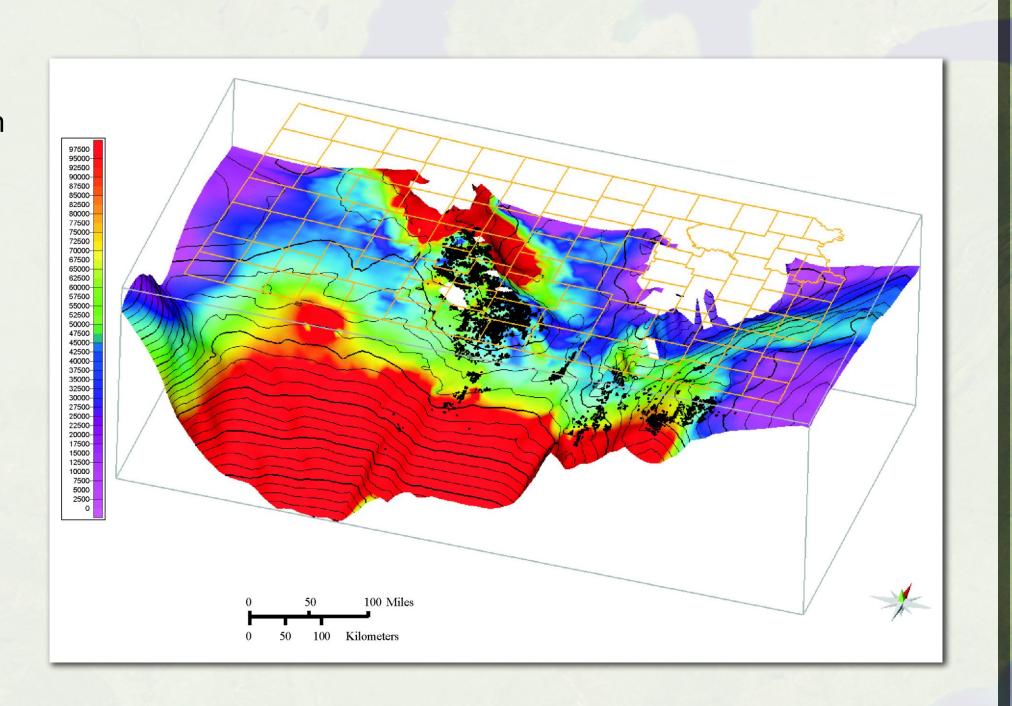# Estimates of the Carbon Dioxide Sequestration Capacity for Lower Paleozoic Aquifer Systems in the Midcontinent Region of North America

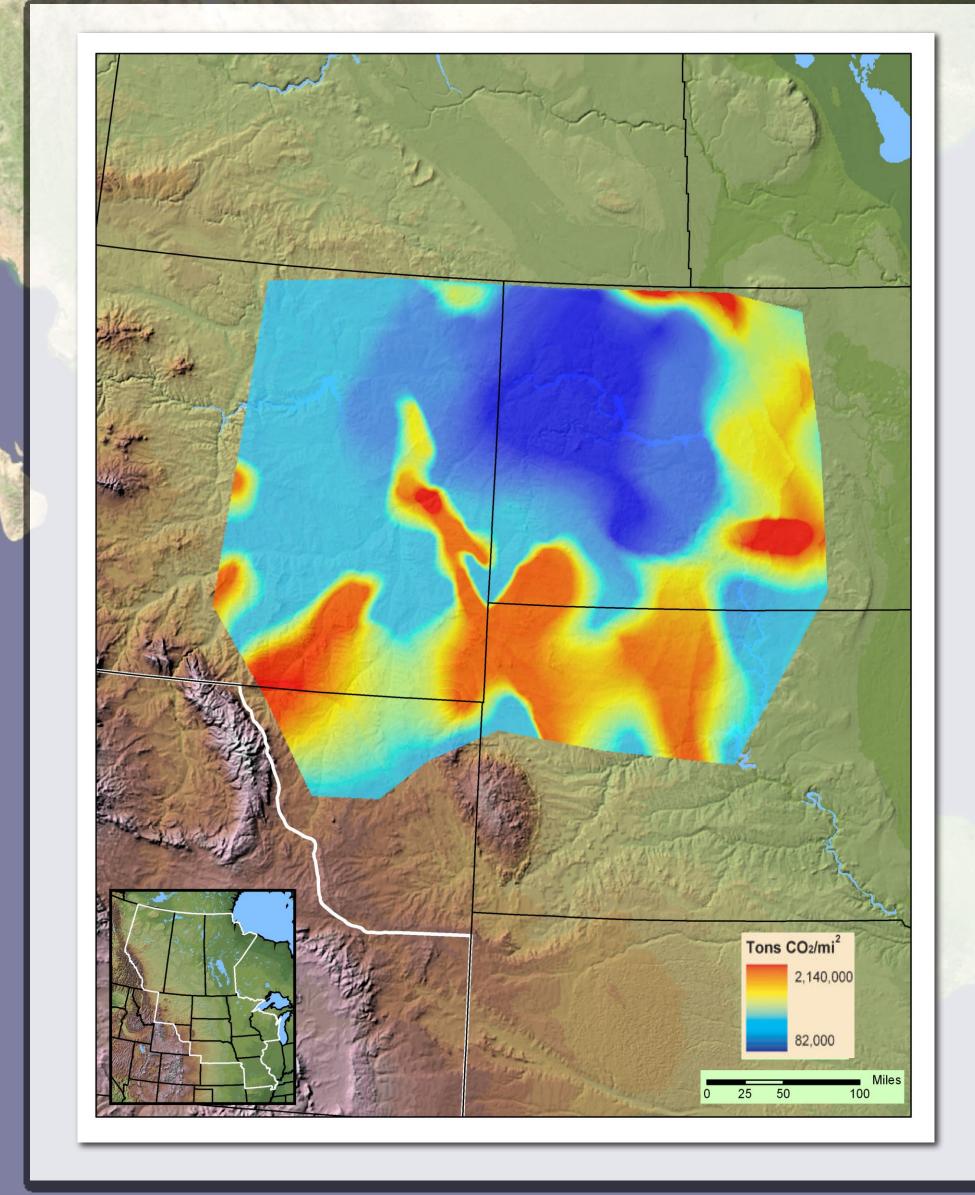Steven A. Smith, Energy & Environmental Research Center
Timothy R. Carr, Kansas Geological Survey
David W. Fischer, Fischer Oil and Gas
Jeremy D. Bartley, Kansas Geological Survey
Wesley D. Peck, Energy & Environmental Research Center
James A. Sorensen, Energy & Environmental Research Center

Saline aquifers within the midcontinent region of North America have the potential to store vast quantities of anthropogenic $CO_2$. The lower Paleozoic (Cambrian to Mississippian) aquifer systems extend from Oklahoma and Missouri in the south to Saskatchewan and Manitoba, Canada, in the north, comprising one of the largest regional-scale aquifer systems in North America. Understanding the regional continuity, hydrodynamic characteristics, and fluid properties of these regional-scale aquifer systems provides a basis to evaluate $CO_2$ sequestration potential. Large-scale relational databases and geographic information system tools are used to integrate temperature, pressure, and water geochemistry data from numerous wells to evaluate the potential for geologic $CO_2$ sequestration in the midcontinent lower Paleozoic aquifer systems. Specifically, a model was developed using a calculation that relates the pore volume in the formation as the product of area, thickness, and porosity, and the solubility of $CO_2$ in the formation water (which considerd the effect of salinity), at spatially varying pressures and temperatures. Depth to the top of the formation was also considered, with a minimum depth of 2500 feet being set to protect potable aquifers. Additional tools provide the ability to query and analyze geochemical data within a geospatial context from numerous saline aquifers across North America. Specific stratigraphic units that were evaluated include the Madison Group (Mississippian) and the Arbuckle Group (Cambrian-Ordovician). The reconnaissance-level potential storage capacity estimates generated by this approach suggest that over 100 billion tons of $CO_2$ could be stored in these aquifer systems.

### Arbuckle Group



**Estimates of Potential $CO_2$ Storage (Metric Tons $CO_2$ per square mile)**

Map showing the estimated sequestration potential in the Arbuckle saline aquifer in metric tons $CO_2$ per square mile. The Spatial Data Engine (SDE) layer is generated for each 5-square-mile area from aquifer temperature, pressure, salinity, porosity, and thickness data. The entire Arbuckle aquifer underlying Kansas has the potential to sequester a large quantity of $CO_2$. Sequestration volume assumes solubility in brine. If the displacement is more significant, the volumes will be significantly greater. The layer can be accessed and queried through the NATCARB Web site (NATCARB, 2005) (Carr and White, 2003). The interpreted flow pattern of fluids in the lower Ozark Plateau is superposed on the map.
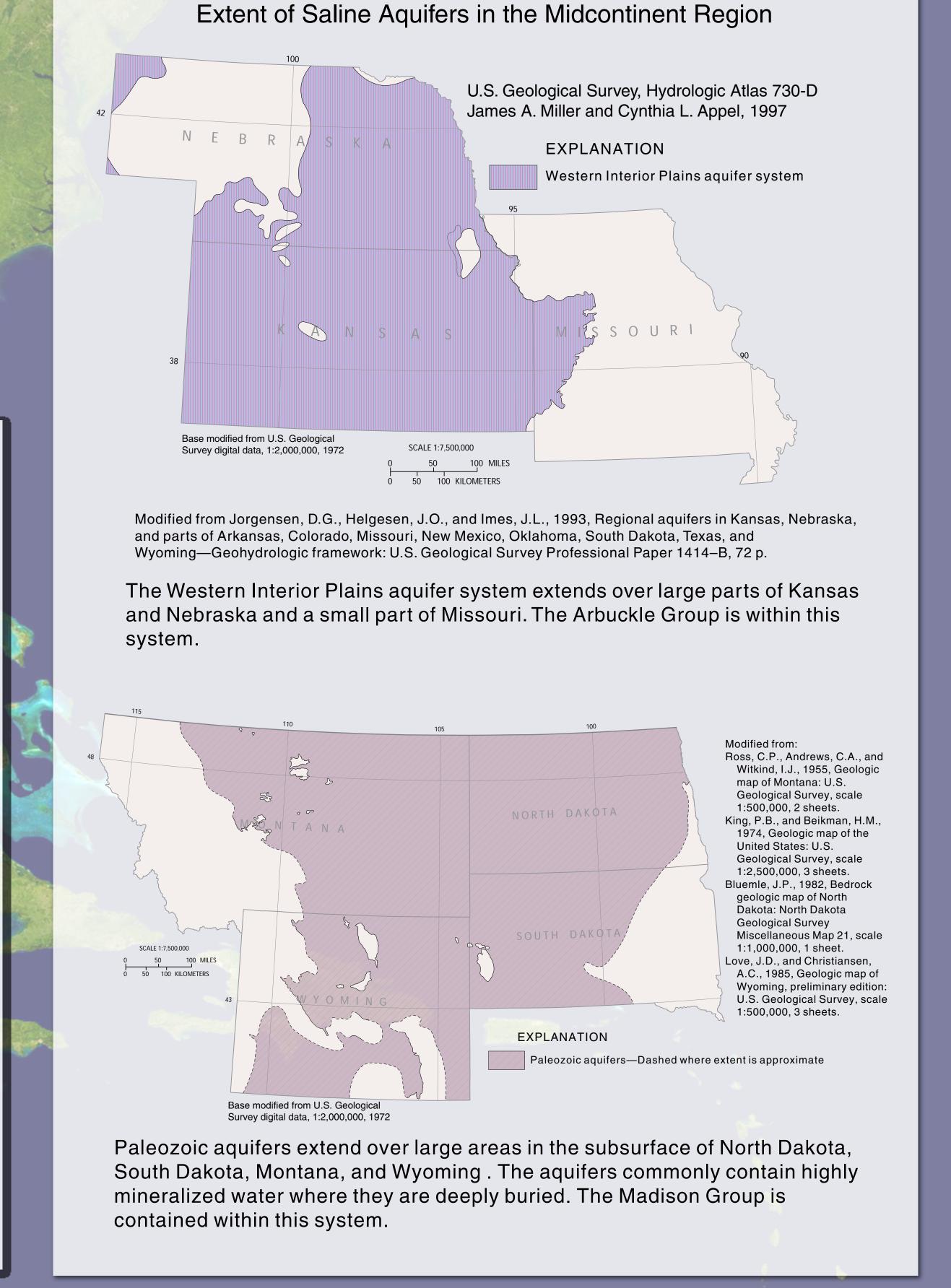


Three-dimensional view of the TDS in Arbuckle brines (color CI = 2500 ppm TDS) overlain on Arbuckle structure with leases producing oil from the Arbuckle Group (black dots, n = 12,436). All TDS concentrations more than 100,000 ppm are shown in red. Data were derived from Arbuckle water samples from various sources (2929 records). The map is constructed with a grid of 26,400 ft (8050 m). Note the coincidence of changes in the TDS concentration and the limits of known Arbuckle production. Dense brines around the Cambridge arch, along the northeastern side of the central Kansas uplift, and in small northwest-trending areas of increased TDS concentrations on the uplift seem to be associated with areas of vertical structural movement where the Arbuckle has been removed by erosion. Areas where Arbuckle has been removed by erosion are shown as white. Sample data are available from the Kansas brine database (Kansas Geological Survey, 2005b).

### Saline Aquifer Storage Calculation

$$Q = 7758 * (A) * (T) *(\phi) * (CO_2s)$$

Where:

Q = $CO_2$ remaining in the aquifer after injection (ft³)

7758 = (43,560 ft²/acre) X (.178 bbl/ft³)

A = Area (acres)

T = Producing interval thickness (ft)

$\phi$ = Average reservoir porosity (%)

$CO_2s$ = Solubility of $CO_2$ (ft³/bbl)

As part of the National Carbon Sequestration Database Project (NATCARB) and Plains $CO_2$ Reduction (PCOR) Partnership, programs were developed to estimate the amount of $CO_2$ that could be sequestered in saline aquifers. Estimates are based on subsurface temperature, pressure, and salinity conditions. For the $CO_2$ solubility calculator, an RDBMS table was constructed to provide estimates of the solubility of $CO_2$ in aquifer water; data for the table are empirical (Martin, 1951; Johnson et al., 1952; Crawford et al., 1963; Holm, 1963; Chang et al., 1996). The tool is designed to access an automated lookup table to estimate the solubility of $CO_2$ as a function of pressure and temperature interpolating between empirical curves. Second, the $CO_2$ solubility is corrected to the salinity of the water (independent of pressure and temperature). This approach provides a first-order estimate for solubility of $CO_2$ in saline aquifers. The program is used to generate the sequestration maps shown here.

### Extent of Saline Aquifers in the Midcontinent Region



U.S. Geological Survey, Hydrologic Atlas 730-D
James A. Miller and Cynthia L. Appel, 1997

EXPLANATION
Western Interior Plains aquifer system

Modified from Jorgensen, D.G., Helgesen, J.O., and Imes, J.L., 1993, Regional aquifers in Kansas, Nebraska, and parts of Arkansas, Colorado, Missouri, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming—Geohydrologic framework: U.S. Geological Survey Professional Paper 1414–B, 72 p.

The Western Interior Plains aquifer system extends over large parts of Kansas and Nebraska and a small part of Missouri. The Arbuckle Group is within this system.



EXPLANATION
Paleozoic aquifers—Dashed where extent is approximate

Modified from:
Ross, C.P., Andrews, C.A., and Witkind, I.J., 1955, Geologic map of Montana: U.S. Geological Survey, scale 1:500,000, 2 sheets.
King, P.B., and Beikman, H.M., 1974, Geologic map of the United States: U.S. Geological Survey, scale 1:2,500,000, 3 sheets.
Bluemle, J.P., 1982, Bedrock geologic map of North Dakota: North Dakota Geological Survey Miscellaneous Map 21, scale 1:1,000,000, 1 sheet.
Love, J.D., and Christiansen, A.C., 1985, Geologic map of Wyoming, preliminary edition: U.S. Geological Survey, scale 1:500,000, 3 sheets.

Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

Paleozoic aquifers extend over large areas in the subsurface of North Dakota, South Dakota, Montana, and Wyoming. The aquifers commonly contain highly mineralized water where they are deeply buried. The Madison Group is contained within this system.
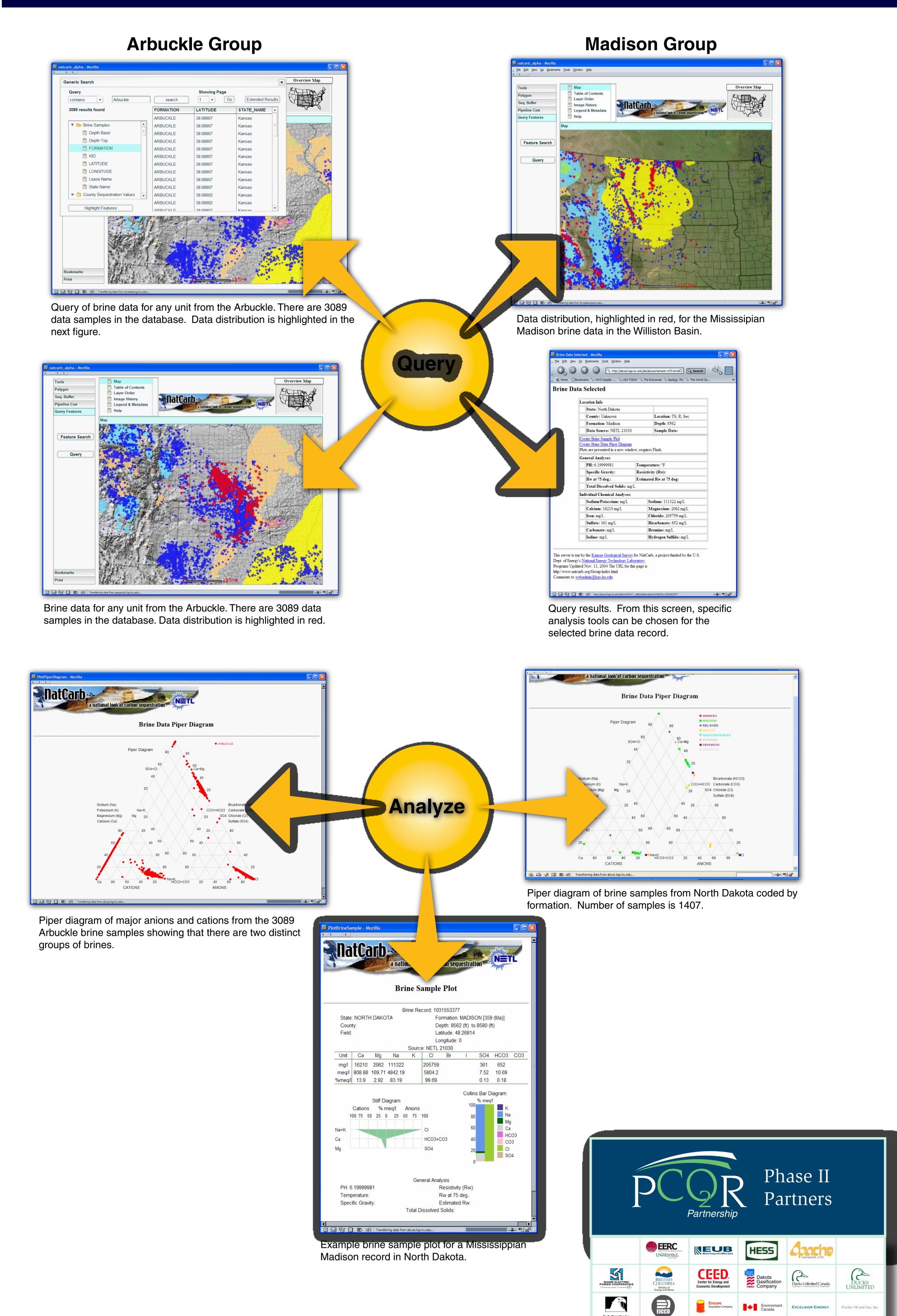
The Mississippian Madison saline aquifer system has been evaluated for its regional continuity, hydrodynamic characteristics, fluid properties, and ultimate storage capacities using published data. The unique lateral extent of these aquifers, the current understanding of their storage potential gained through produced fluid disposal, and the geographic proximity to major $CO_2$ sources suggest they may be suitable sinks for future storage needs. For example, reconnaissance-level calculations on the Mississippian system in the Williston Basin and Powder River Basin suggest the potential to store upwards of 60 billion tons of $CO_2$ over the evaluated region. Results of the evaluation are stored in an interactive Web-based decision support system for future integration into a national carbon sequestration database.



**Tons $CO_2$/mi²**

### Arbuckle Group

### Madison Group



Query of brine data for any unit from the Arbuckle. There are 3089 data samples in the database. Data distribution is highlighted in the next figure.

Data distribution, highlighted in red, for the Mississippian Madison brine data in the Williston Basin.

Brine data for any unit from the Arbuckle. There are 3089 data samples in the database. Data distribution is highlighted in red.

Query results. From this screen, specific analysis tools can be chosen for the selected brine data record.

**Query**

**Analyze**

Piper diagram of major anions and cations from the 3089 Arbuckle brine samples showing that there are two distinct groups of brines.

Piper diagram of brine samples from North Dakota coded by formation. Number of samples is 1407.

Example brine sample plot for a Mississippian Madison record in North Dakota.